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TAXONOMY AND BIOLOGY OF A NEW SPECIES OF *ZAPHANERA* (HEMIPTERA: ALEYRODIDAE) AND ITS ASSOCIATION WITH THE WIDESPREAD DEATH OF WESTERN MYALL TREES, *ACACIA PAPYROCARPA*, NEAR ROXBY DOWNS, SOUTH AUSTRALIA

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Summary

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An outbreak of western myall whitefly, a new species of *Zaphanera* (Hemiptera: Aleyrodidae), is associated with dieback and death of western myall trees, *Acacia papyrocarpa* Bentham, in a desert area of about 10,000 km^2 in South Australia. Both young and mature trees up to several hundred years old are affected. Death of foliage appears to be related to large numbers of the whitefly feeding on phyllodes. A new species of the parasitoid *Zarhopaloides* (Hymenoptera: Encyrtidae) emerged from whitefly pupae and appears to be the first encyrtid authenticated as a true parasitoid of aleyrodids. Possible causes of this outbreak are discussed and include (1) a temporary parasitoid asynchrony with its host population, (2) the possibility that western myall whitefly has been newly-introduced to the area on another plant host and has adapted to western myall trees and (3) that the outbreak is symptomatic of a widespread decline in the health of trees. All life-history stages of the new species of *Zaphanera* and the new species of the parasitoid *Zarhopaloides* are described.

KEY WORDS: *Zaphanera*, *Zarhopaloides*, *Acacia papyrocarpa* Bentham, western myall whitefly, western myall tree, outbreak, tree death.

Introduction

Western myall, *Acacia papyrocarpa* Bentham, is a desert adapted tree of chenopod shrublands on calcareous soils in the 150-300 mm (predominantly winter) rainfall zones of northern Spencer Gulf, along the margins of the Nullarbor Plain of South Australia, and in the Eastern Goldfields of Western Australia. Much of this area is used for grazing sheep and cattle for which the trees provide shelter. Western myall shares the eastern parts of its range with mulga, *Acacia aneura* F. Muell., to form a mixed species woodland.

Western myall trees are slow-growing and may reach 5-6 m before becoming recumbent (Lange & Sparrow 1992). Age estimates of mature trees vary from 250 years (Coleman *et al.* 1996[1]) to 350+ years (Ireland 1997[2]). Foliar growth flushes are produced by the tree during summer (November to February) and appear to be independent of rainfall (Ireland 1997[2])

This paper describes an outbreak of an apparently native whitefly species in the genus *Zaphanera* on western myall which has killed trees over a wide area of north-eastern South Australia. There is no historical evidence of previous outbreaks of this species on western myall trees anywhere in Australia (nor of any other insect capable of killing so many trees so quickly). We are not aware of previous reports of any whitefly species causing widespread death of perennial trees. Both the whitefly and its encyrtid wasp parasitoid are described as new and possible reasons for the outbreak are discussed.

Materials and Methods

Taxonomy

Terminology for whitefly morphology follows that of Martin (1999) and that for the encyrtid parasitoid is after Noyes & Hayat (1994). The following abbreviations are used for institutions:

ANIC, Australian National Insect Collection, CSIRO Entomology, Canberra;

BMNH, The Natural History Museum, London, UK;

USNM, US National Museum of Natural History, Washington, DC;

WINC, Waite Insect and Nematode Collection, Waite Campus, SA.

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[1] COLEMAN, D., IRELAND, C. & WEST, N. E. (1996) The lifespan of western myall (*Acacia papyrocarpa* Benth.). "Rangelands in a sustainable biosphere". Proceedings of the Fifth International Rangeland Congress Salt Lake City, Utah, USA 23-28 July, 1995. Volume 1 contributed presentations. 1996, 99-100. (Society for Range Management, Denver, Colorado, USA) (unpub.).

[2] IRELAND, C. (1997). Sustaining the western myall woodlands: ecology and management. PhD Thesis, Department of Environmental Science and Rangeland Management, Adelaide University (unpub.).

The following abbreviations are used in the parasitoid description:
AL - aedeagus length
EL - maximum eye length
EW - maximum eye width
F1-6 - funicle segments 1-6, i.e. the first six segments after the pedicel
FV - minimum frontovertex width
FWL - fore wing length
FWW - fore wing width
GL - gonostylus length
HW - head width
HWL - hind wing length
HWW - hind wing width
MT - mid tibia length
MS - malar space
OCL - minimum distance between posterior ocellus and occipital margin
OL - ovipositor length
OOL - minimum distance between posterior ocellus and eye margin
POL - minimum distance between posterior ocelli
SL - scape length
SW - maximum scape width

Biology

The life cycle of western myall whitefly was constructed from ten population samples taken at approximately monthly intervals during September-April and less frequently during May-August over the period December 1999 to December 2000. Whitefly population samples were taken from 20 mature trees, individually marked, just outside Roxby Downs township. At each sampling time, a healthy growing shoot was cut from each tree at approximately 2.5 m height and individually stored in a paper bag. The samples were examined within two days of collection. On each shoot, five sub-terminal mature phyllodes were examined and the number and stage of whiteflies were noted using x 20 magnification under a binocular microscope.

This intensity of sampling yielded estimates of mean numbers of whitefly with the following standard errors: for eggs, 20% of the mean per phyllode, for each of second and third instar larvae, 25% of mean and for the pupal stage, 19% of the mean number per phyllode. First instar (mobile) larvae were rarely observed. The presence of any adults flying around trees was also noted.

During the year 2000, ground surveys along station tracks delimited the extent of the whitefly infestation. Trees with symptomatic dieback were inspected and the presence of a whitefly noted. Non-symptomatic trees were examined in every copse encountered along the route, generally allowing at least 5 km after each positive record before resuming sampling. A tree was chosen 10-20 m away from the track but beyond this, no special sampling scheme was used. On each tree, 50 phyllodes were examined with the aid of a hand lens and, if any stage(s) of whitefly were present, the tree was counted as positive. If no whiteflies were found on the tree examined, a nearby tree was sampled. If this was positive, the site was scored as positive. The site was scored as negative only if no evidence of the whitefly was found on either tree.

Zaphanera papyrocarpae Martin sp. nov.
(FIGS 1-4, 7-17)

Holotype: ♂ puparium, Billakilina Station, 30° 16' S, 136° 17' E, South Australia, on phyllodes of *Acacia papyrocarpa*, 26.iv.2000 (J. H. Martin 7406) (slide-mounted, ANIC).

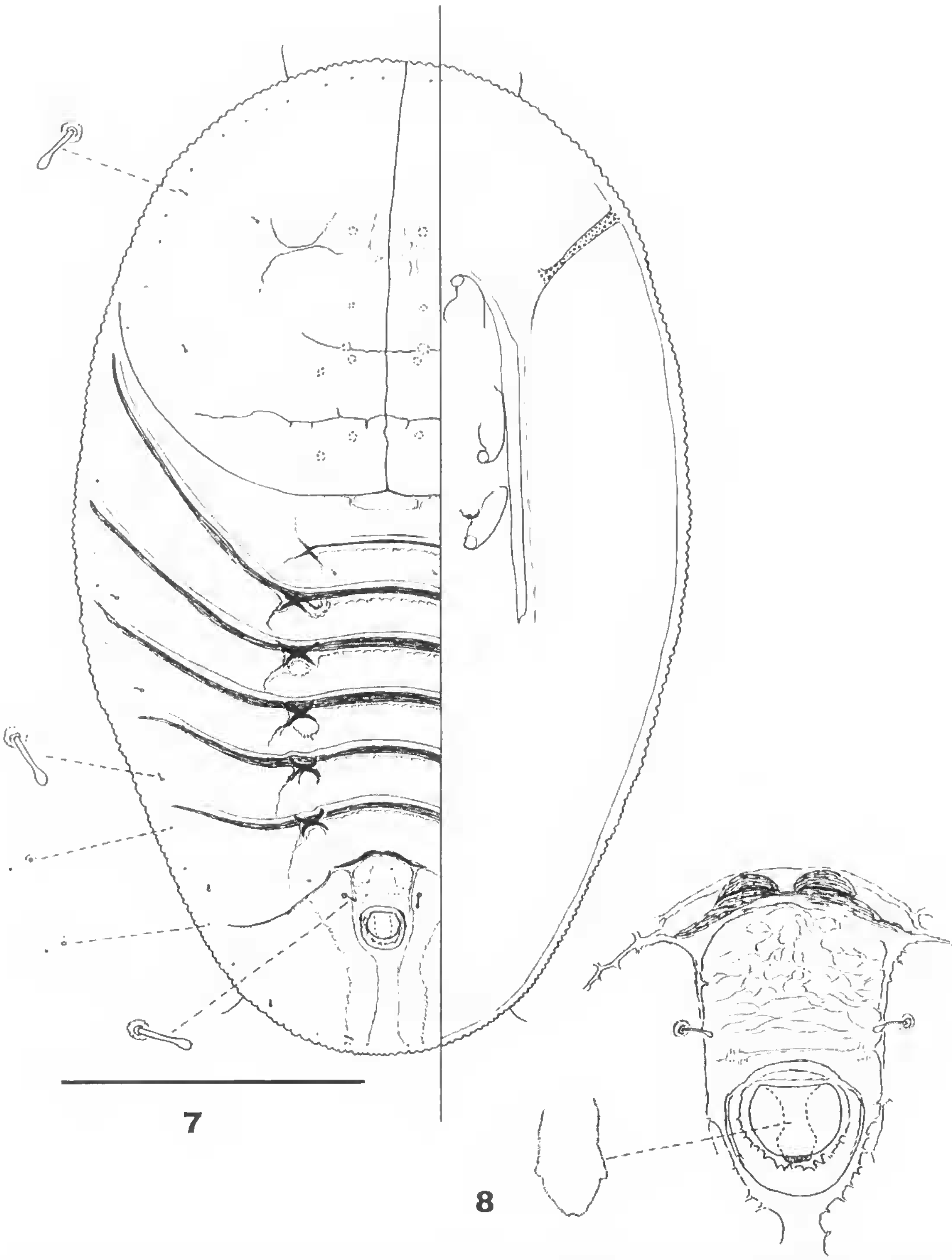
Paratypes: South Australia (all slide-mounted): 9 ♂♂ (puparia), 16 ♀♀ (puparia) same data as holotype (ANIC, BMNH, USNM, WINC); 3 ♂♂ (puparia), 6 ♀♀ (puparia) Roxby Downs township, 27.iv.2000 (J. H. Martin) (BMNH, WINC), 25 puparia, 6 third-instar larvae, 1 second-instar larva, vicinity of Roxby Downs, v.1999 (J. Zwar) (ANIC); 29 puparia, 6 L3/puparium mid-moults, 9 third-instar larvae, 11 first-instar larvae, vicinity of Roxby Downs 20.x.1999 (P. Bailey) (BMNH, WINC); 14 puparia, 2 L3/puparium mid-moults, 4 third-instar larvae, vicinity of Roxby Downs 11.i.2000 (J. Hardy) (BMNH, WINC); 11 adult ♂♂, 9 adult ♀♀, vicinity of Roxby Downs, 14.ii.2000 (P. Bailey) (BMNH); 1 L3/puparium mid-moult, 6 third-instar larvae, 37 second-instar larvae, 5 first-instar larvae, Roxby Downs township, 25.iv.2000 (J. H. Martin) (BMNH).

Other material: A large amount of dry material of all larval stages from the above collection sites is held in BMNH and WINC.

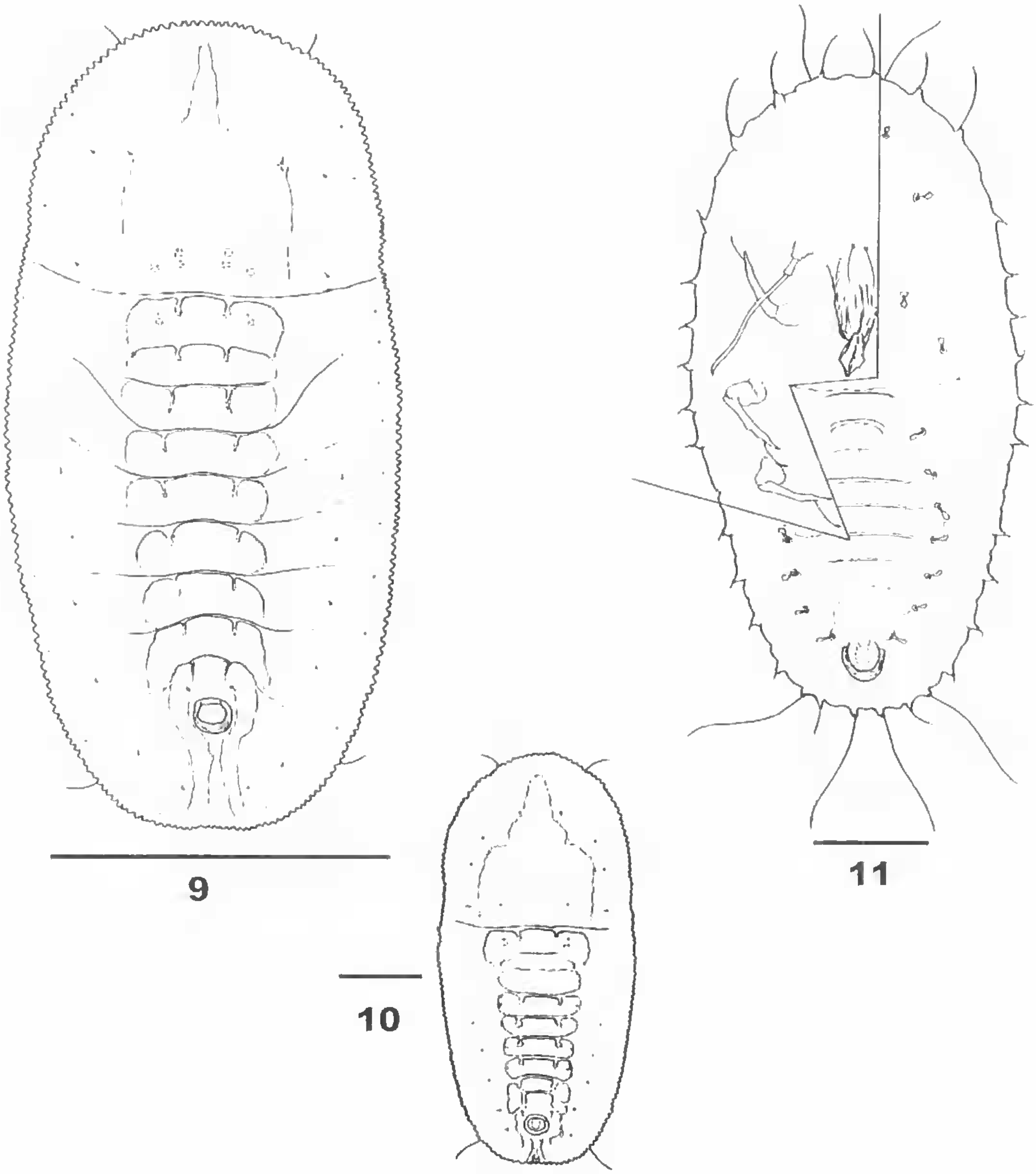
Puparium (Figs 3, 4, 7, 8)

Shortly after the L3/L4 moult shining black, almost flat, but with increasing maturity becoming markedly convex and developing covering of sparse greyish meal (Fig. 3); entire cephalothorax falling away upon emergence of adults (Fig. 3); sexually dimorphic, male puparia 1.42-1.57 mm long, 0.81-0.96 mm wide, widest opposite confluence of longitudinal and transverse moulting sutures (Fig. 7); antennal apices underlying median part of abdominal segment II/III (n=16); female puparia 1.72-1.95 mm x 1.05-1.18 mm, widest abdominally; antennal apices terminating between middle and hind legs (n=14); puparia of both sexes 1.50-1.80 x as long as wide; margin crenulate throughout, typically 6-8 rounded teeth occupying 0.1 mm of abdominal

Figs 1-6. Life history stages and damage of western myall whitefly, *Zaphanera papyrocarpae* Martin sp. nov. 1. Eggs on a phyllode of western myall. 2. One second instar (on left) and third instar larvae on a phyllode. 3. Adult female emerging from puparium. 4. Eggs and pupae encrusting phyllodes. 5. Damage by *Z. papyrocarpae*. A western myall tree in Roxby Downs township with early symptoms of dieback associated with *Z. papyrocarpae* on phyllodes (this tree died six months later). 6. Dead (left) and dying (right) western myall trees in pastoral lands of South Australia. Scale bars = 0.5 mm, 1; 1 mm, 2-4; 1 m, 5, 6.



Figs 7, 8. *Zaphanera papyrocarpae* Martin sp. nov., puparium. 7. Complete puparium with expanded detail of capitate setae and geminate pore/porette pairs. 8. Dorsal detail of vasiform orifice region (drawn from a teneral puparium). Scale bar = 0.5 mm.



Figs 9-11. *Zaphanera papyrocarpae* Martin sp. nov., instars I-III (not drawn to same scale). 9. Third-instar larva, dorsum. 10. Second-instar larva, dorsum. 11. First-instar larva. Scale bars = 0.5 mm, 9; 0.1 mm, 10, 11.

margin; teeth rather irregular but not modified at caudal and thoracic tracheal openings at margin; anterior and posterior marginal setae present; dorsal chaetotaxy difficult to discern in mature puparia; all dorsal setae short, capitate; single pair of 8th abdominal setae placed anterior and slightly lateral to vasiform orifice; abdomen usually with 6 outer submarginal pairs, cephalothorax usually with a single outer submarginal pair and 2 subdorsal pairs of setae (Fig. 7), but cephalic (submedian) setae absent; dorsum with longitudinal moulting suture reaching puparial margin; transverse moulting sutures curving anterolaterally and reaching margin; abdominal segmentation as shown, the intersegmental divisions of abdominal segments II/III to VI/VII exaggerated, thickened, suture-like, III curving sharply anteriad and almost reaching puparial margin; abdominal division VII/VIII less exaggerated but also closely approaching margin, submedian pockets variably marked depending on degree of maturity; abdominal segment VII not reduced in length medially; abdominal rhachis evident, with lateral arms short (not to be confused with long intersegmental divisions); pair of submedian posteriorly directed tubercles on posterior edge of each of abdominal segments I-VI abut with a pair of similar anteriorly directed tubercles on the anterior edge of each of segments II-VII, often appearing as 6 pairs of characteristic darker "X" figures; submedian abdominal depressions present but camouflaged by these tubercles; cephalothoracic equivalents clearly marked by irregular rings of paler markings; submargin with row of tiny pores, seen to be geminate pore/porette pairs only in teneral specimens; similar pores seen in small groups adjacent to submedian depressions; vasiform orifice cordate, slightly elevated posterolaterally, fully occupied by operculum which obscures lingula; in teneral specimens lingula as shown in Fig. 8, without apical setae (characters of vasiform orifice essentially the same throughout larval stages); vasiform orifice about 0.06 mm long in male, 0.07 mm in female, inset from posterior puparial margin by 2.0-3.1 x its own length in male, 3.3-4.1 x in female; caudal furrow defined by shallow ridge to either side but without markings; eyespot markings absent. On venter antennae dimorphic as discussed above, bases placed lateral to fore legs; legs each with apical adhesion pad; middle and hind legs each with tiny basal seta and spine; ventral abdominal setae placed slightly anterior to dorsal 8th abdominal setae; caudal and thoracic tracheal folds present, narrow, paler than adjacent cuticle and punctuated by darker ovoid markings; when venter separated from the dorsum, submedian area seen to be much paler than submargin/subdorsum (a character typical for *Zaphanera*).

Third-instar larva (Figs 2, 9)

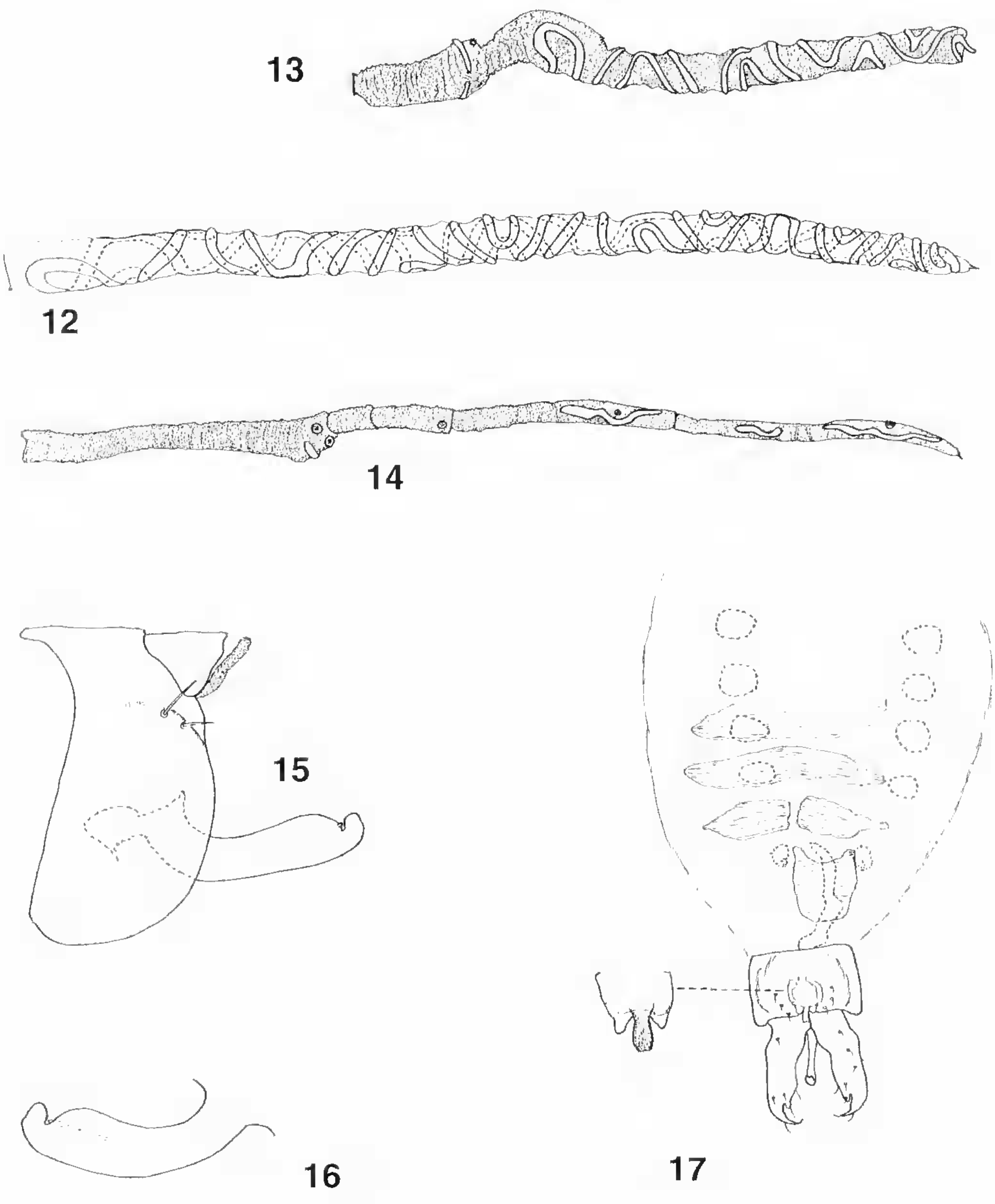
Elongate oval, outline subtly constricted slightly anterior to long meso-metathoracic division (easily mistaken for cephalothoracic-abdominal division but hind legs clearly underlie apparent first abdominal segment), at which point coarse marginal crenulations are somewhat finer in some individuals; third-instar exuvia observed to fold at this meso-metathoracic division; sexual dimorphism apparent, individuals falling into range 1.04-1.09 mm long, 0.49-0.53 mm wide (presumed male) or 1.18-1.27 mm long, 0.56-0.63 mm wide (presumed female), all 2.00-2.13 x as long as wide (n=16); cuticle pale, but with median pigmented patch overlying mouthparts and fore legs, another on abdominal segments I-III, and brownish median pigmentation present between vasiform orifice and abdominal division VII/VIII; anterior and posterior marginal setae present; dorsal chaetotaxy same as in puparia, setae short and blunt or very slightly capitate; abdominal intersegmental divisions II/III to VI/VII pronounced, extending into outer subdorsum; submedian abdominal depressions distinct, thoracic equivalents marked as in puparia; submedian zone rhachisform; submargin with row of geminate pore/porettes; legs typical for third-instar, rather triangular, fore and middle pairs with apical pads directed laterad but hind pair directed posteriorly; antennae vestigial, placed anterior to bases of fore legs.

Second-instar larva (Figs 2, 10)

Elongate oval, outline subtly constricted anterior to long meso-metathoracic division, which is only intersegmental division extending into subdorsum; cuticle mostly pale, but with some dusky pigmentation on rhachisform submedian area; size 0.60-0.70 mm x 0.27-0.33 mm (n=34); margin coarsely crenulate; anterior and posterior marginal setae present, large with respect to body size; dorsal chaetotaxy apparently as in puparium and third-instar, but only 2 pairs of thoracic and single pair of submedian 8th abdominal setae distinct in all specimens; other individuals with 6 pairs of subdorsal abdominal and third thoracic pair of setal bases always visible but setae themselves variably, or not, developed; few geminate pore/porette pairs present around periphery of rhachis; legs subtriangular, apical pads distinct; antennae vestigial, anterior to fore legs, lateral to basal (anterior) part of rostral apparatus.

First-instar larva (Fig. 11)

Pale, 0.34-0.40 mm x 0.14-0.19 mm (n=16), margin with 16 pairs of finger-like protrusions, smooth between them; each marginal protrusion bearing seta, anterior and posterior-most 3 pairs being long and hair-like; remainder short, slightly capitate; between the anterior-most 2 pairs of protrusion-borne setae is a pair arising from the smooth margin, presumed to be the anterior marginal setae; on this basis, posterior marginal setae absent; as in second and third instars, most pronounced intersegmental division is between meso- and metathorax; dorsum with 4 pairs of cephalothoracic and 7 pairs of abdominal subdorsal capitate setae; ventrally, appendages reflect mobility of this stage, each leg with single articulation between coxa/femur and tibia/tarsus; coxa discernible; tarsus not distinct from tibia but distal segment of leg with apparent single claw-like apex and distinct clubbed subapical digitule; each antenna with 3 distinct segments,



Figs 12-17. *Zaphanera papyrocarpae* Martin sp. nov., adult characters. 12. Male antennal segment III. 13. Male antennal segment IV, with single convoluted sensorium shown. 14. Female antennal segments III-VII. 15. Lateral view of male genital segment. 16, Lateral view of male aedeagus. 17. Dorsal view of male abdomen, with expanded detail of operculum and lingula.

distal one longest and extending posteriorly to base of middle leg; rostral base and ventral abdominal setae fine, at least as long as vasiform orifice.

Egg (Fig. 1)

Black, borne at apex of a long pedicel angled such that egg itself almost touches the phyllode surface; laid on to phyllode surfaces, often interspersed with larval stages.

Adult male (Figs 12, 13, 15-17)

1.73-1.87 mm long (including parameres), antennae 0.81-0.90 mm, ultimate rostral segment 0.100-0.125 mm (n=9); wings typical for Aleyrodinae, with main vein of fore and hind wing unbranched, wings unpigmented; abdomen bearing 4 pairs of oval wax glands, about 0.70-0.90 mm long (Fig. 17); parameres, aedeagus, operculum and lingula as illustrated (Figs 15-17); entire abdomen, anterior to genital segment, very finely spinulose, appearing greyish under lower magnification; antennae with only 4 visible segments, segment III usually distinctly angled in its basal third and with single, circular, ciliate sensorium proximad of this "elbow" (Fig. 13); the 2 flagellar segments each with much convoluted, but apparently single, sensorium looping repeatedly around the segment (Figs 12, 13).

Adult female (Figs 3, 14)

1.78-1.97 mm long, antennae 0.62-0.75 mm, ultimate rostral segment 0.10-0.13 mm (n = 8); wing characters as in male; abdomen bearing only 2 pairs of oval wax glands, about 0.10 mm long; abdominal surface very finely spinulose, as in male; antennae 7-segmented, IV and V much shorter than remainder of flagellar segments; usually with segment VII bearing 2 sinuous sensoria (the distal one being the longest), segment VI with one sinuous sensorium and segment III with a subapical sensorium of irregular outline but not elongate.

Etymology

Named after its host plant, *Acacia papyrocarpa* (Leguminosae: Mimosoideae), the western myall, from which it takes both its specific name and suggested common name, western myall whitefly.

Taxonomic relationships

Amongst the four described Australian species of *Zaphanera*, the puparia of *Z. papyrocarpae* sp. nov. appear closest to *Z. niger* (Maskell) and nearly key as such in Martin's (1999) key. *Zaphanera papyrocarpae* shares with *Z. niger* a lack of submedian glandular patches, presence of submedian pairs of abutting abdominal tubercles and exceptionally pronounced intersegmental divisions II/III to VI/VII. The puparia of *Z. papyrocarpae* develop aligned along the narrow, subcylindrical phyllodes of the western myall. It was initially suspected that the new species might be a variant of *Z. niger*, developing greater convexity and a more elongate puparial outline in response to its feeding environment. However, closer examination has indicated several other, consistent, characters that separate these two taxa. The most striking characteristic of the puparia of *Z. papyrocarpae* is the extreme forward-curving of the transverse moulting sutures and abdominal intersegmental divisions II/III to V/VI, a feature not seen in any other examined members of the genus, whether described or not. Puparia of *Z. papyrocarpae* further differ from those of *Z. niger* in only possessing three pairs of cephalothoracic setae of which two pairs are displaced into subdorsum (*Z. niger* has six cephalothoracic pairs, all submarginal), in not possessing a submarginal pair of setae on abdominal segment III (present in *Z. niger*) and in having a short lateral rhachis arm issuing from the outer basal edge of each abdominal anteriorly-directed tubercle (rhachis completely undeveloped in *Z. niger*). Puparia of *Z. niger* have very small, but distinct, submedian abdominal depressions mid way between the intersegmental divisions, whereas the depressions in *Z. papyrocarpae* are difficult to see, given the greater development of the submedian abdominal tubercles. Third-instar larvae of *Z. papyrocarpae* are elongate-oval (more broadly rectangular in *Z. niger*), with characteristic submedian pigmentation (completely pale in *Z. niger*) and elongate submedian abdominal depressions (circular in *Z. niger*) and with a pronounced submedian rhachis (completely absent in *Z. niger*).

To date, the adults of *Z. papyrocarpae* are the only imagos known for any species of *Zaphanera*. Thus, no conclusions can yet be drawn as to whether any of the several unusual adult characters described above are generic or specific. Certainly, the presence of only two pairs of abdominal wax glands in the females is not usual in the Aleyrodinae and the characteristic convoluted antennal sensoria of both sexes are similarly remarkable.

Life cycle of Zaphanera papyrocarpae

Western myall whitefly had two distinct generations per year during the study (Fig. 18). An autumn-winter generation commenced with eggs laid in late February and a spring-summer generation started from eggs laid in October. The eggs hatch into mobile first instar larvae that could sometimes be seen dispersing on phyllodes. The sedentary second and third instar larvae (Fig. 2) developed more slowly in winter than in the summer. The fourth instar larvae (= 'pupae') were conspicuous on

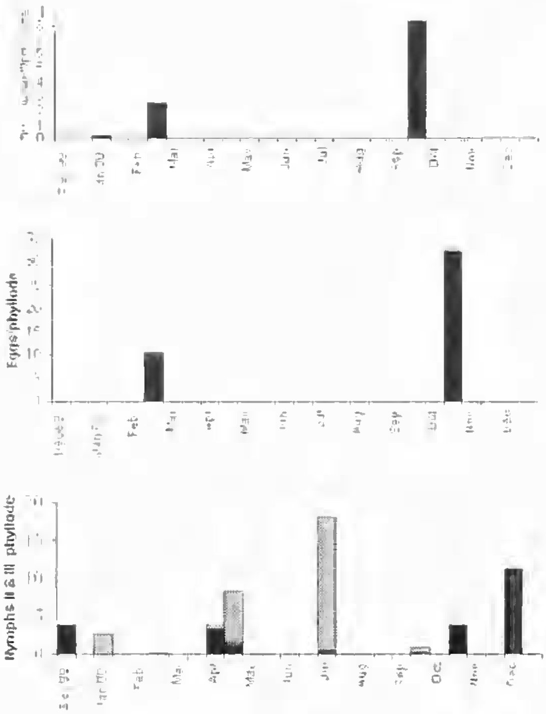


Fig. 18. Generations of *Zaphanera papyrocarpae* Martin sp. nov. Adults emerge from pupae during late summer and spring (top figure) and lay eggs (middle), from which develop the autumn winter and spring-summer generations of larvae (bottom). Second instar larvae are shown shaded and third instars in black.

phyllodes, where large numbers often appeared to encrust the phyllode (Fig. 4). This stage was closely associated with leaf, shoot and branch death. No honeydew exudate was observed associated with any stage of whitefly development, nor were ants closely associated with whitefly larvae. Adults (Fig. 3) lived for only one or two days when allowed to emerge in the laboratory at 24° C and provided with moisture. The February 2000 sample was taken immediately following rain and the adults were observed flying in small clouds immediately above shoots on trees.

Timing of generations and life history stages can be roughly estimated from Fig. 18. Taking into account the period between egg layings, the autumn-winter generation takes approximately seven months and the spring-summer generation five months. Eggs appear to hatch over a period of no more than four weeks. Duration of the second instar is about 6-8 weeks in March-April and 4-6 weeks in September-November. Duration of the third instar is about 20 weeks in April-September and eight weeks in November-December. Duration of the pupal stage is four weeks in September but up to eight weeks in January-February.

Demarcation of outbreak

Trees on which *Z. papyrocarpae* were recorded are contained in an area of approximately 10,000 km north and north-west of Roxby Downs (Fig. 19). Trees showing symptoms of dieback and death associated with western myall whitefly populations were found throughout the area. Outside this area, no evidence of any whitefly species could be found on any *A. papyrocarpa* tree.

Within the area of infestation, mulga trees (*A. aneura*) were sometimes found in close association with western myall, in some cases with touching foliage. These mulga trees were examined but *Z. papyrocarpae* was never recorded. However, another (undescribed) species of *Zaphanera* was occasionally found on them.

Damage

Field observations confirmed the association of *Z. papyrocarpae* with dieback and death of trees, first reported by Ireland in 1998 (unpub.). Of several hundred trees examined during the study, those with dieback symptoms were always associated with the presence of western myall whitefly. Symptoms on mature trees included initial yellowing of phyllodes on small areas of the tree, followed by death of foliage on branches (Fig. 5) and then death of woody branches (Fig. 6). Once dead patches appear on mature or young trees, death of the whole tree may occur within one year. As a rough estimate, areas of foliage with an average of 3-5 pupae per phyllode were likely to die.

Zarhopaloides anaxenor Noyes sp. nov. (FIGS 20-27)

Holotype: ♀, Roxby Downs, South Australia, ex *Zaphanera papyrocarpae*, on *Acacia papyrocarpa* 22.x.1999, J. Zwar (ANIC).

Paratypes: South Australia: 6 ♀♀, 10 ♂♂, same data as holotype (ANIC, BMNH, WINC).

Female

Length 1.13-1.40 mm (1.40 mm in holotype). Frontovertex pale orange-yellow, paler in ocellar area; face, genae and temples concolorous but slightly paler; occiput black bordered pale orange yellow; radicle and most of scape concolorous with face, but outer face of scape with broad, dark brown dorsal stripe extending along most of dorsal margin, pedicel with basal two thirds dorsally and laterally dark brown, almost black, ventrally and at apex dusky, pale orange; flagellum testaceous brown, proximal segments darker; anterior half of pronotum black, posterior half translucent pale, yellow or white and clothed in translucent white setae; mesoscutum

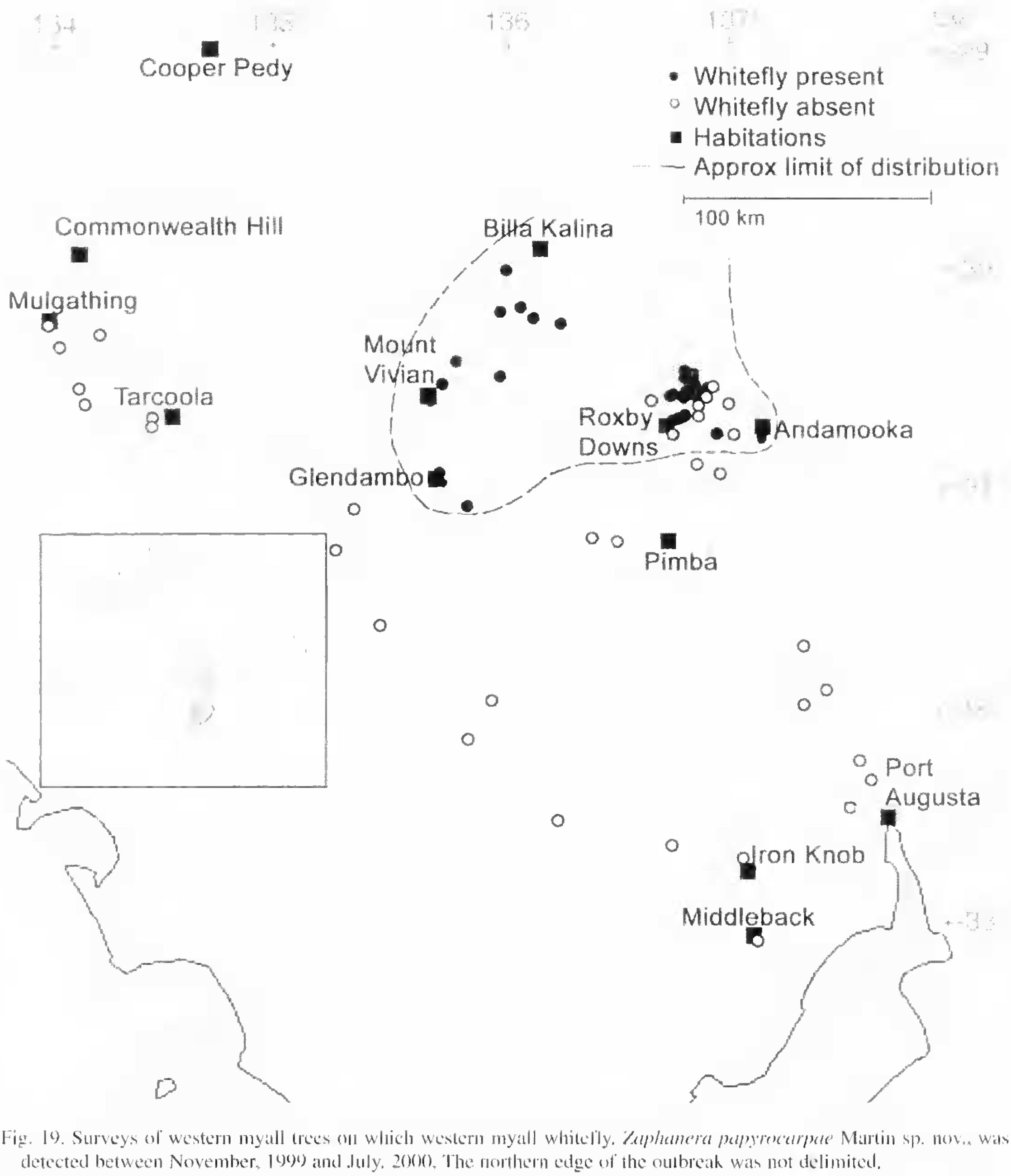


Fig. 19. Surveys of western myall trees on which western myall whitefly, *Zaphanera papyrocarpae* Martin sp. nov., was detected between November, 1999 and July, 2000. The northern edge of the outbreak was not delimited.

shining, metallic blue-green in anterior two-thirds, yellow in posterior one-third and along lateral margins, extreme posterior margin black; axillae yellow; scutellum mostly shining, metallic blue-green mixed, posteriorly purple, apex and lateral margins posteriorly yellow; tegula white with brown apical spot; dorsum of thorax clothed in dense, translucent, white setae; metanotum medially yellow, laterally black; prepectus translucent white, anteriorly dark brown; mesopleuron with small yellow spot below tegula but generally metallic green, bluish posteriorly, slightly purplish dorsally; prosternum metallic green; fore leg with coxa and femur yellow, tibia yellow mixed dusky and margined brown dorsally and ventrally, tarsus pale brown mixed yellow, pretarsus dark brown; mesosternum metallic green; mid coxa metallic green and clothed in conspicuous translucent, white setae, apex yellow, femur yellow, tibia slightly dusky yellow with an inconspicuous brown stripe along most of dorsal margin, tarsus pale yellow with pretarsus dark brown; hind coxa metallic blue-green mixed with purple and clothed with translucent pale brown or whitish setae; hind femur yellow, hind tibia yellow but with narrow brown band at base and two broad, brown bands at one-third and two-thirds its length respectively; tarsus dusky yellow, pretarsus dark brown; wings completely hyaline, venation brown; metapleuron metallic green and clothed in conspicuous translucent white setae; propodeum medially black with slight sheen, greenish towards spiracles, shining blue-green outside spiracle here and clothed in dense, conspicuous, translucent, white setae; gaster dark brown but with strong, metallic blue-green or purplish sheen and clothed in fairly conspicuous, translucent, white setae on basal tergite and laterally; visible part of gonostylus yellow with extreme apex brownish; head about 3.3 x as broad as frontovertex which is about 1.6 x as long as broad and narrowest between anterior ocellus and top of scrobes, ocelli forming an acute angle of about 70°; antenna (Fig. 20) with scape almost cylindrical, a little less than 5 x as long as broad; F1-5 subquadrate, distal segments largest, F6 clearly transverse and largest; clava with apical sensory area distinct giving apex slightly obliquely truncate appearance; linear sensilla on F3-6 and clava; mandibles (Fig. 21) tridentate, upper tooth somewhat truncate; relative measurements: HW=76, FV=23, POL=12.5, OOL=2.5, OCL=7, MS=25, EL=42, EW=39, SL=29, SW=6.5. Visible part of mesoscutum about 2 x as broad as long; scutellum hardly shorter than mesoscutum and slightly broader than long; fore wing about 2.6 x as long as broad; linea calva not interrupted, but closed by one or two lines of setae near posterior wing margin; basal cell densely and evenly pilose; venation as in Fig. 22; relative measurements: FWL=185, FWW=71, HWL=135, HWW=42; gaster about three-fifths as long as thorax; ovipositor as in Fig. 24 exserted part less than one-fifth as long as mid tibial spur; hypopygium (Fig. 23) reaching about half way along gaster; relative measurements (paratype): OL=44, MT=39, GL=8.

Male

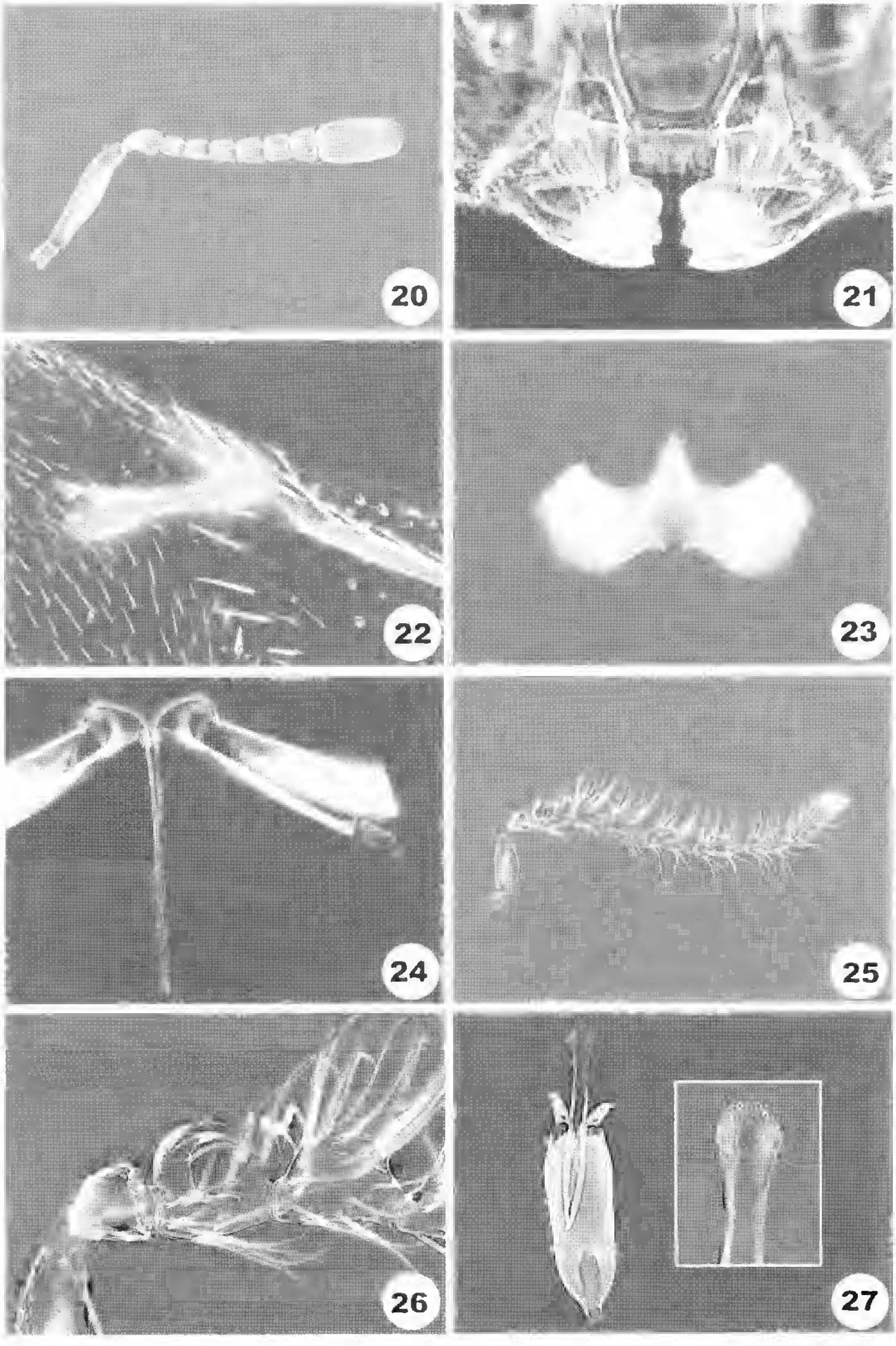
Length 0.98-1.29 mm; very similar to female except for some small differences in colouration, wider frontovertex, antennal structure (Fig. 25), less dense setae in basal cell of fore wing and structure of genitalia; colour as in female but for small, metallic, green spot immediately behind anterior ocellus, flagellum generally yellow with extreme apex of clava brown; mesoscutum, axillae and scutellum completely metallic blue-green; fore tibia with only a small subapical, brown spot on dorsal margin, otherwise fore and mid tibia yellow; hardly marked with brown; head about 2.3 x as broad as frontovertex which is about 1.3 x as long as broad and narrowest about level with anterior margins of posterior ocelli; scrobes broad, subparallel and moderately deep; a small depression between each scrobe dorsally and eye which possibly accommodates F1 in resting position; ocelli forming angle of about 95°, antennal torulus separated from mouth margin by slightly more than 1.5 x its own length with ventral margin a little above lower eye margin; antenna (Fig. 25) with scape short and only about 2 x as long as broad; flagellum clothed in long setae which on proximal segments dorsally are clearly longer than diameter of segments; F1 subquadrate and with deep, dorsal groove giving it a U-shaped appearance (Fig. 26); F2-F6 about 1.5 x as long as broad but giving the rest of the funicle a slightly serrate appearance; clava subcylindrical and a little less than 3 x as long as broad, with apex more or less transversely truncate; relative measurements: HW=71, FV=31, POL=19, OOL=3, OCL=7, MS=20, EL=35, EW=30, SL=20, SW=9.5; fore wing about 2 x as long as broad; basal cell with setae conspicuously less dense than in apical half of wing with distinct naked areas near base and below parastigma; relative measurements: FWL=68, FWW=31, HWL=47, HWW=14; aedeagus about half as long as mid tibia, its apex broadly spatulate (Fig. 27); relative measurements: AL=32, MT=70.

Host

Zarhopaloides anaxenor was reared from *Zaphanera papyrocarpae* Martin sp. nov. (Hemiptera: Aleyrodidae) on *Acacia papyrocarpa*.

Taxonomic relationships

Zarhopaloides has been characterised by Noyes & Hayat (1984) and Dahms & Gordh (1997) and includes four previously described species. Females of *Z. anaxenor* sp. nov. are most similar to those of *Z. speciosus* Girault in general structure and colouration of the head and dorsum of the thorax. The two species can be distinguished on the distribution of linear sensilla on the funicle and colouration of the hind tibiae and fore wing. In *Z. anaxenor* linear sensilla are present only on F3-F6, the hind tibia has a pair of distinct brown bands and the fore wing is completely hyaline, whereas in *Z. speciosus* all funicle segments possess linear sensilla, the hind tibia is almost completely brown without any distinct bands and the fore wing has a large, subcircular infuscate area below the marginal



Figs 20-27. *Zarhopaloides anaxenor* Noyes sp. nov. 20. Female antenna. 21. Mandibles. 22. Fore wing venation. 23. Female hypopygium. 24. Female ovipositor. 25. Male antenna. 26. First funicle segment, male. 27. Male genitalia (inset - apex of aedeagus).

vein. Females of the other species differ in having the frontovertex and face largely metallic green (*Z. cinctithorax* (Girault)), a subcircular infuscate area below the marginal vein (*Z. auricaput* (Girault)) or at least F1 strongly transverse and about 2 x as broad as long (*Z. auricaput* and *Z. axillaris* Girault). Males are known only for *Z. cinctithorax* and have the antennal flagellum filiform with F1 unmodified and clothed in setae which are very much shorter than the diameter of the segments.

There are few authenticated records of Encyrtidae as parasitoids of whiteflies. To date, species of 11 encyrtid genera have been recorded as whitefly parasitoids (Noyes 1998). Most of these are likely to be erroneous observations or one-off 'accidents' where species that normally attack diaspidid scales or other smaller coccoids may attempt to parasitise aleyrodids when their normal hosts are scarce. Other than some undescribed species of *Metaphycus* frequently reared from whiteflies in South America (material in BMNH) and *Rhopus erianthi* (Myarsteva) (comb. nov. from *Platyrhopus*) from central Asia, *Z. anaxenor* appears to be the first species to be authenticated as a true parasitoid of aleyrodids.

Rates of parasitism

Parasitised pupae were identified by the circular exit hole and predated pupae by a jagged hole. The only parasitoid that emerged from samples of *Z. papyrocarpae* was *Zaphopaloides anaxenor* Noyes sp. nov. The rates of parasitism of pupae of *Z. papyrocarpae* are shown for two periods in Table 1. No parasitoid exit holes were detected in any stage other than the pupa.

TABLE 1. *Apparent mortality of Z.* papyrocarpae *pupae at Roxby Downs for two sampling periods during 2000*

Date collected	Total pupae (n)	% parasitism	% predation
15 Feb. 2000	94	4	< 1%
26 Oct. 2000	281	10	< 1%

Discussion

The outbreak of western myall whitefly and the associated death of many of its host trees is unusual and the cause(s) have not been established with any certainty during this study. A number of possible causes are discussed below.

Failure of natural enemies

The parasitoid *Z. anaxenor* was the only natural enemy identified during this study but the biology of this wasp has not yet been studied in detail. The rate of parasitism on western myall whitefly was no greater than 10% during this study and so it is unlikely to have been significant in reducing numbers of this species.

There was no evidence that the outbreak of *Z. papyrocarpae* could be attributed to failure of generalist predators or parasitoids. The presence of predators was inferred from jagged holes in puparia but predation of younger stages of whitefly was unlikely to have been detected because evidence of these stages may fall from the phyllode. Eggs of brown lacewings (*Micromus* spp. - Neuroptera: Hemerobiidae) were frequently observed on sampled phyllodes. Thus, the influence of general predators may have been greater than indicated by these results. However, any failure of these predators should have been in evidence on other species of trees. At a number of sites in the Roxby Downs area, western myall (*A. papyrocarpa*) trees infested with whitefly grow in close proximity to mulga (*A. aneura*), sometimes with overlapping canopies. Careful searching of such mulga trees yielded a different species of whitefly but in very low in numbers. This mulga-associated whitefly was clearly not undergoing any increase in population which might be expected if generalist natural enemies had been absent from the area.

A new introduction

This study has not eliminated the possibility that the original plant host of the whitefly was a species of *Acacia* other than *A. papyrocarpa*. Searches of naturally-occurring *Acacia* species in the area of Roxby Downs did not yield any *Z. papyrocarpae* on hosts other than western myall. It is possible that *Acacia* species exotic to the Roxby Downs region may have been introduced and carried the whitefly to the area. This whitefly may then have switched to *Acacia papyrocarpa* but not to any other *Acacia* species in the area. Martin (1999) notes that the related species *Z. niger* has three recorded hosts: *Acacia pycnantha* Bentham, *A. longifolia* (Andrews) Willd. and *A. melanoxylon* R. Br. More data on the host range of *Z. papyrocarpae* need to be collected to test the hypothesis that this whitefly has recently adapted to *A. papyrocarpa*.

Tree health

Dying western myall trees were first noticed in the township of Roxby Downs in 1998 (Ireland unpub.). Roxby Downs is a mining town constructed during the past 20 years around existing communities of mature western myall trees. A large copper-uranium mine is located some 20 km from Roxby Downs and, beyond the limits of the mine area itself, there is no evidence of aerial or effluent emissions in the atmosphere or groundwater which might affect tree health.

Some trees within the township had their extensive root systems disturbed by road works and other trees had changed water availability, mainly an increase, resulting from garden irrigation. While the western myall trees in Roxby Downs township live in a disturbed environment, the same is not true of the symptomatic trees up to 100 km distant in the pastoral areas to the north and north-west of the town where land use has changed little during the past 100 years, with sheep, cattle, rabbits and red kangaroos as the main grazing and browsing macrofauna. White (1993) argues that nutritional status of host plants may cause outbreaks of insect populations. In the present case, western myall trees under some form of stress may have provided optimum conditions for the hitherto uncommon *Z. papyrocarpae* to increase its reproductive rate temporarily to outpace its natural enemies. However, the area containing symptomatic trees covers about 10,000 km^2, including both recently disturbed township areas and pastoral areas whose land use has remained unchanged for many years. Age of trees does not appear to be a factor, as both younger (1-2 m high) and older trees, up to 6 m high, and at least 160 years old (Lange & Sparrow 1992) or older (Coleman *et al.* 1996), sustain high whitefly numbers and exhibit dieback and death. There have been no discernible changes in rainfall patterns for the past 70 years. Therefore, since conditions for tree growth have remained much the same, there is no evidence to support the suggestion that poor tree health was a contributing factor to the outbreak of western myall whitefly and consequent death of trees.

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